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Review of the Ph.D. thesis

„Effect of the chemical composition and processing parameters on the microstructure and mechanical properties of the bars subjected to innovative XTP process"

by Radosław Rozmus

General remarks

The reviewed work was created under the supervision of Professor Krzysztof Radwański at the Faculty of Materials Science and Engineering of the Silesian University of Technology. The Professor's research team has been conducting research on industrial applications for many years. The constantly growing demand for high-quality metal materials operating in extreme conditions poses new challenges for materials engineering related to the need to develop new materials and technologies for their production.

The subject of this dissertation concerns one of the main trends in research conducted at the Faculty of Materials Science and Engineering of the Silesian University of Technology - the search for new types of steel and their production technologies.

The author of the dissertation set the research goal to develop a one-step thermomechanical rolling (XTP – Xtrem Performance Technology) process for rolling bars of conventional 7MnB8 steel with a modified chemical composition, characterized by a reduced transition temperature to the brittle state without significant changes in the values of other mechanical properties compared to conventional 7MnB8 steel.

In order to achieve the aim of the work, Radosław Rozmus initially developed a research program that included preliminary microstructural tests of industrial 7MnB8 steel and numerical simulation of various parameters of the XTP process of its production in order to characterize the structural dependence on these parameters. Based on the results obtained, four groups of process parameters were proposed and industrial tests were carried out using 7MnB8 steel. This allowed the development of new chemical compositions with modified contents of

Mn, Mo, Ti, Nb and V, from which rods of new steels were made as input to the XTP process. Then, industrial tests of new steel grades were carried out with process parameters for which the lowest transition temperature to the brittle state was obtained for 7MnB8 steel. After rolling, the structure and mechanical properties of bars with modified chemical composition were examined. The obtained results were analyzed and, on this basis, final conclusions were formulated in the form of technological guidelines.

In my opinion, the reviewed dissertation concerns problems of great importance, not only scientifically but, above all, in application. It covers a very current research topic in materials engineering - the development of new materials and their production technologies.

Editorial comments

The study is complete and written understandably. Its organization is classic. After a short introduction, the author presents the state of knowledge in the researched field based on an extensive literature review. Then, he formulates the reasons for undertaking research, presents a thesis and formulates the purpose of the work. Finally, a description of the obtained results and their critical discussion were presented.

The dissertation is very interesting to read, especially since it is written in good language and does not contain editorial errors. It is worth emphasizing that numerous references to literature are current and appropriately selected.

Objectives and thesis

The three-roll rolling technology is well established and found in the literature. The principle of bar production is similar to the XTP process implemented at Swiss Steel. Despite common knowledge about this type of material processing, there is little knowledge in the literature about rolling steel with a bainitic structure. In the field of single-stage XTP rolling of bainitic steels, knowledge is insufficient and is limited only to the first works that were created as a result of cooperation between Steeltec and Swiss Steel using 7MnB8 steel. The first test results of 7MnB8 XTP bainitic steel are promising and show the potential of this new type of steel products.

The review of the state of knowledge conducted by the author of the dissertation shows that none of the publications discusses issues related to the impact of the refinement of the bainitic structure on impact strength. This was the direct motivation of the PhD student's to put forward the hypothesis that "The selection of the content of alloy additions in bainitic steel, combined with the development of parameters of the innovative one-stage thermomechanical XTP rolling process, makes it possible to obtain a gradient structure leading to a reduction in the temperature of the material's transition to a brittle state without significant changes in the values of other basic values. mechanical properties of the bars compared to conventional 7MnB8 steel".

To verify this thesis, Radosław Rozmus developed a research program aimed at obtaining steel with increased impact strength at low temperatures compared to conventional 7Mn B8 steel produced by the industrial partner, Swiss Steel. The research was carried out to optimize the rolling process of this steel with a modified chemical composition (mainly changes in the composition of elements such as Mn, Mo, Nb, V and Ti) in order to improve the ductile brittle transition temperature (DBTT) at low temperatures down to -100°C, while maintaining the strength properties obtained for 7MnB8 steel.

The author of the dissertation carried out a very ambitious research program, which included thermodynamic calculations, numerical simulation of various parameters of the XTP process and experimental research: light and electron microscopy, dilatometric tests, tests of mechanical properties (hardness, static tensile test, impact strength) and industrial tests of the XTP process.

The research techniques were appropriately selected and allowed the author to successfully implement the established research program, which included three stages:

1. Preliminary examination of the condition of industrial steel 7MnB8 (characterization of grain growth kinetics and determination of the austenitization temperature and simulation of industrial tests in a dilatometer).
2. Optimization of XTP process parameters (conducting industrial tests with the proposed process parameters and characterization of the microstructure and mechanical properties of the manufactured bars).
3. Development of the modified composition of 7MNB8 steel (preparation of five laboratory castings, industrial tests of the XTP process for new grades of 7MnB8 steel, testing of the microstructure and mechanical properties of bars with modified chemical composition).

The obtained research results were subjected to in-depth analysis and, on this basis, final conclusions were formulated.

Summing up, the aim and the scope of the study meet all the requirements set forth to research works intended to form the basis of a doctoral dissertation.

Most important results

Radosław Rozmus has accomplished a very ambitious research program and discussed thoroughly the results obtained. It should be noted that they have a very important cognitive value. The PhD student investigated the influence of the chemical composition of steel (7MnB8 steel was selected as a reference) on the formation of the microstructure and its properties after the XTP process. Both the optimization of the chemical composition of this steel (the research was carried out on five types of steel) and the selection of the parameters of the XTP process were used to verify the research hypothesis in which the author of the dissertation postulated that controlling these parameters would ensure obtaining "a gradient structure leading to a reduction in the transition temperature of the material into the brittle state with no significant changes in the values of other basic mechanical properties of the bars, relative to conventional 7MnB8 steel". The experiments conducted by Radosław Rozmus are very well summarized in the diagram presented in Figure 187 (Chapter 7 "Summary"). It shows the influence of the chemical composition of the steel on the microstructure and mechanical properties of the steel after XTP rolling (with process parameters: TA = 980 °C, TR = 700 °C and accelerated cooling ~ 7.6 °C/s).

The analysis of the state of technology carried out by Radosław Rozmus on many levels allowed to characterize the most important variables from the point of view of obtaining a specific structure ensuring the required mechanical properties of the tested steel.

The author of the dissertation began verifying the thesis by numerically simulating the rolling process in order to determine the optimal process parameters. In the next stage of the research, the PhD student optimized the XTP process parameters. After rolling, a gradient microstructure was obtained. Deformations mainly accumulate in the near-surface region, where the greatest grain refinement is observed. Applying cross-rolling improves the mechanical properties of the material.

From the practical point of view, a very important conclusion was that limiting the cooling rate to ~ 2.3 °C/s, reduces the thickness of the refined near-surface zone by about four times, so that the bar structure on the cross-section is characterized by greater homogeneity. The doctoral student also determined the influence of the parameters of the rolling process of 7MnB8 steel on its impact strength - the lowest value (-120 °C) of ductile brittle transition temperature (DBTT) was obtained for the parameters: TA = 980 °C, TR = 700 °C and accelerated cooling ~ 7.6 °C/s.

An important achievement of Radoslaw Rozmus was performing a comparative analysis of the microstructure and mechanical properties of steels with different contents of Mn, Mo, Nb, V and Ti subjected to processing with the use of a group of technological parameters for which the lowest DBTT for industrial steel was obtained. The author of the dissertation showed that changing the configuration of alloying additives with a reduction in Ti content leads to the elimination of Ti_2CS and coarse TiN particles in the microstructure. The presence of these phases is undesirable in steel, where the resistance to dynamic loads is required.

The author of the dissertation showed that the role of other alloying elements is no less important. A different bar microstructure was found to be obtained from steel with increased Mn content up to 2.9 wt. %. Increasing the hardenability by increasing Mn from ~ 1.9 to 2.9 wt. % leads to complex bainite morphology (Upper Bainite, Lower Bainite and Granular Bainite). In turn, a higher Mo content improves the impact strength of steel. However, the V in steel after the rolling process was observed as a substitution of Ti and Nb in MC and M_2N precipitations.

Research carried out by Radosław Rozmus showed that the lowest DBTT of -150°C and -180°C are found in S660 and S659 steels, respectively, in which Nb additions were used (high in S659 and low in S660) and the Ti content was reduced below 0.03% wt. %.

In my opinion, the important research achievement of the PhD student is the development of technological parameters of the one-stage XTP rolling process, as well as the optimization of the chemical composition of 7MnB8 steel in terms of obtaining an improvement in DBTT, while preserving the strength properties obtained in preliminary work for 7MnB8 steel.

The experiment carried out by the doctoral student allows for the conclusion that the thesis "The selection of the alloy content of bainitic steel in the document presenting the parameters of the one-stage thermomechanical rolling process using the XTP method allows for an extended gradient structure resulting from a reduction in the temperature of the material in brittle states without the impact of changes in values resulting from the influence of rods in regarding conventional 7MnB8 steel" has been positively verified.

To sum up, I can say that the results of experiments and analyzes conducted by Radosław Rozmus have a very large potential for implementation in industry and bring new knowledge in the area of selecting the chemical composition of modern steels and controlling thermo-mechanical processes in order to optimize their functional properties.

Specific comments

In Chapter 3 "The aim of the study", the PhD student writes that "In the field of single-step XTP rolling of bainitic steels, knowledge is insufficient and limited only to the first works that were carried out as a result of cooperation between Steeltec and Swiss Steel using 7MnB8 steel. First results of bainitic steel 7MnB8 XTP are promising and show the potential of this new class of steel products."
Therefore, it seems justified that 7MnB8 steel was selected for testing. However, there is a question - whether the research methodology used in the experiment is universal enough to be applied to other types of steel, including bainitic.

The selection of XTP process parameters and modification of the chemical composition of 7Mn8B steel were to demonstrate that "it is possible during XTP process to obtain a gradient structure leading to a reduction in the transition temperature of the material into the brittle state with no significant changes in the values of other basic mechanical properties of the bars, relative to conventional 7MnB8 steel".
Why was DBTT chosen? Can the determined parameters of the XTP process and optimization of the chemical composition of the tested steel affect its other strength parameters, e.g. fatigue resistance?

Could the PhD student indicate potential directions for further research aimed at improving the functional properties of the final product (in particular various grades of bainitic steel)? Are they in the material or technological part of the thermo-mechanical treatment process?

Final opinion

I consider the doctoral study "Effect of the chemical composition and processing parameters on the microstructure and mechanical properties of the bars subjected to innovative XTP process" presented by Radosław Rozmus has great scientific and practical value. Not only is his study well-aimed, but the research aims are competently formulated. The results of the PhD student's research proved that by selecting the elements in bainitic steel (modification of the chemical composition of 7MNB8 steel) and one-step optimization of the XTP process, it is possible to obtain a structure leading to a reduction in the transition temperature of this material into the brittle state with no significant changes in the values of other basic mechanical properties, relative to conventional 7MnB8 steel.

In my opinion, the Ph.D. study presented by Radosław Rozmus is a significant contribution to the development of modern materials. Based on the above remarks I can state that the Ph.D. dissertation submitted by Radosław Rozmus satisfies the requirements set forth to Ph.D. dissertations defined in the respective regulations and recommendations of the Council of Scientific Excellence currently in force in Poland.

I recommend the dissertation of Radosław Rozmus to be submitted to public debate before the Scientific Council of Materials Science and Engineering of the Silesian University of Technology.

In my opinion, the results of the experiments and analyses performed by Radosław Rozmus in his dissertation make a significant contribution to the development of knowledge in the field of modern steel.

Therefore, I am asking the Scientific Council of Materials Engineering of Silesian University of Technology to distinguish the dissertation entitled "Effect of the chemical composition and processing parameters on the microstructure and mechanical properties of the bars subjected to innovative XTP process" by Radosław Rozmus.

Jarosław Mizera